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(57) Abstract

Methods for preparing dry powders having hydrophobic and hydrophilic components comprise combining solutions or suspensions of the components and spray drying them simultaneously in a spray drier. The hydrophilic component is dissolved in an aqueous solution and the hydrophobic component suspended therein. The method provides dry powders having relatively uniform characteristics.

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PROCESSES FOR SPRAY DRYING AQUEOUS SUSPENSIONS OF HYDROPHOBIC DRUGS WITH HYDROPHILIC EXCIPIENTS AND COMPOSITIONS PREPARED BY SUCH PROCESSES

This application is a continuation-in-part or Provisional Application No. 60/034,837, filed on December 31, 1996, the full disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to dry powder compositions and methods for their preparation and use. In particular, the present invention relates to methods for spray drying pharmaceutical and other compositions comprising a hydrophobic drug or other component and a hydrophilic excipient or other component.

Over the years, certain drugs have been sold in formulations suitable for oral inhalation (pulmonary delivery) to treat various conditions in humans. Such pulmonary drug delivery formulations are designed to be inhaled by the patient so that the active drug within the dispersion reaches the lung. It has been found that certain drugs delivered to the lung are readily absorbed through the alveolar region directly into blood circulation. Such pulmonary delivery can be effective both for systemic delivery and for localized delivery to treat diseases of the lungs.

Pulmonary drug delivery can itself be achieved by different approaches, including liquid nebulizers, aerosol-based metered dose inhalers (MDI's), and dry powder dispersion devices. Aerosol-based MDI's are losing favor because they rely on the use of chlorofluorocarbons (CFC's), which are being banned because of their adverse effect on the ozone layer. Dry powder dispersion devices, which do not rely on CFC aerosol technology, are promising for delivering drugs that may be readily formulated as dry powders.

The ability to deliver pharmaceutical compositions as dry powders, however, is problematic in certain respects. The dosage of many pharmaceutical compositions is often critical, so it is desirable that dry powder delivery systems be able to accurately, precisely, and reliably deliver the intended amount of drug. Moreover, many pharmaceutical compositions are quite expensive. Thus, the ability to efficiently formulate, process, package, and deliver the dry powders with a minimal loss of drug is critical. With dry powder drug delivery, both the delivered dose efficiency, i.e. the percentage of drug from a unit dose receptacle which is aerosolized and delivered from a delivery device, and the median particle size distribution, i.e. the deviation from the median size, are critical to the successful delivery of powders to a patient's lungs.

A particularly promising approach for the pulmonary delivery of dry powder drugs utilizes a hand-held device with a hand pump for providing a source of pressurized gas. The pressurized gas is abruptly released through a powder dispersion device, such as a venturi nozzle, and the dispersed powder made available for patient inhalation. While advantageous in many respects, such hand-held devices are problematic in a number of other respects. The particles being delivered are usually less than 5 μm in size, making powder handling and dispersion more difficult than with larger particles. The problems are exacerbated by the relatively small volumes of pressurized gas, which are available using hand-actuated pumps. In particular, venturi dispersion devices are unsuitable for difficult-to-disperse powders when only small volumes of pressurized gas are available with the handpump. Another requirement for hand-held and other powder delivery devices is efficiency. High device efficiency in delivering the drug to the patient with the optimal size distribution for pulmonary delivery is essential for a commercially viable product.

Spray drying is a conventional chemical processing unit operation used to produce dry particulate solids from a variety of liquid and slurry starting materials. The use of

spray drying for the formulation of dry powder pharmaceuticals is known, but has usually been limited to spray drying of hydrophilic drugs in aqueous solutions, usually in combination with hydrophilic excipients. Many drugs, however, are hydrophobic, preventing spray drying in aqueous solutions. While spray drying of hydrophobic materials can often be accomplished using an organic solvent, the use of such non-aqueous solvents generally limits the ability to simultaneously spray dry a hydrophilic excipient.

For these reasons, it would be desirable to provide improved methods for spray drying pharmaceutical and other compositions which comprise both hydrophobic and hydrophilic components, such as hydrophobic drugs and hydrophilic excipients. Such spray drying methods should be compatible with a wide variety of hydrophobic drugs as well as conventional hydrophilic excipients, such as povidone (polyvinylpyrrolidone) and other water soluble polymers, citric acid, mannitol, pectin and other water soluble carbohydrates, and particularly with those excipients which are accepted for use in inhalation formulations, such as lactose, sodium chloride, and sodium citrate. Such spray drying methods will preferably produce particles having a uniform size distribution, with a mean particle size below 10 μm, preferably below 5 μm, and a standard deviation less than or equal to $\pm$ 2 μm. Such powders should further exhibit uniform composition from batch to batch so that any tendency for particles of different compositions and/or sizes to separate in the lungs will have a reproducible impact on the therapeutic effect. Additionally, such spray drying methods should provide for dry powders which are physically and chemically stable and which have low levels of any residual organic solvents or other components which might be used in the spray drying process. At least some of the above objectives will be met by the various embodiments of the present invention which are described in detail below.

2. Description of the Background Art

Methods for spray drying hydrophobic and other drugs and components are described in U.S. Patent Nos. 5,000,888; 5,026,550; 4,670,419, 4,540,602; and 4,486,435. Bloch and Speison (1983) Pharm. Acta Helv 58:14-22 teaches spray drying of hydrochlorothiazide and chlorthalidone (lipophilic drugs) and a hydrophilic adjuvant (pentaerythritol) in azeotropic solvents of dioxane-water and 2-ethoxyethanol-water. A number of Japanese Patent application Abstracts relate to spray drying of hydrophilic-hydrophobic product combinations, including JP 806766; JP 7242568; JP 7101884; JP 7101883; JP 71018982; JP 7101881; and JP 4036233. Other foreign patent publications relevant to spray drying hydrophilic-hydrophobic product combinations include FR 2594693; DE 2209477; and WO 88/07870.

WO 96/09814 describes spray dried pharmaceutical powders. In particular, Example 7 describes spray drying budesonide and lactose in ethanol where the budesonide is partially soluble and the lactose is insoluble. U.S. Patent Nos. 5,260,306; 4,590,206; GB 2 105 189; and EP 072 046 describe a method for spray drying nedocromil sodium to form small particles preferably in the range from 2 to 15 μm for pulmonary delivery. U.S. Patent No. 5,376,386, describes the preparation of particulate polysaccharide carriers for pulmonary drug delivery, where the carriers comprise particles sized from 5 to 1000 μm. Mumenthaler et al. (1994) *Pharm. Res.* 11:12 describes recombinant human growth hormone and recombinant tissue-type plasminogen activator. WO 95/23613 describes preparing an inhalation powder of DNase by spray drying using laboratory-scale equipment. WO 91/16882 describes a method for spray drying proteins and other drugs in liposome carriers.

The following applications assigned to the assignee of the present application each describe that spray drying may be used to prepare dry powders of biological macromolecules; application serial no. 08/644,681, filed on May 8, 1996, which was a continuation-in-part of application serial no. 08/423,515, filed on April 14, 1995; application serial no.

08/383,475, which was a continuation-in-part of application serial no. 08/207,472, filed on March 7, 1994; application serial no. 08/472,563, filed on April 14, 1995, which was a continuation-in-part of application serial no. 08/417,507, filed on April 4, 1995, now abandoned, which was a continuation of application no. 08/044,358, filed on April 7, 1993, now abandoned; application serial no. 08/232,849, filed on April 25, 1994, which was a continuation of application serial no. 07/953,397, now abandoned. WO 94/07514 claims priority from serial no. 07/953,397. WO 95/24183 claims priority from serial nos. 08/207,472 and 08/383,475.

SUMMARY OF THE INVENTION

According to the present invention, methods for spray drying hydrophobic drugs and other materials are provided which overcome at least some of the deficiencies noted above with respect to prior spray drying processes. In particular, the spray drying methods of the present invention permit the simultaneous spray drying of the hydrophobic component with a hydrophilic component, such as a hydrophilic pharmaceutical excipient, under conditions which result in a dry powder comprising mixtures of both the hydrophilic and hydrophobic components. Although the methods of the present invention are particularly useful for forming pharmaceutical compositions where the hydrophobic component is a hydrophobic drug, usually present at from 0.01% to 95% of the powder, and the hydrophilic component is a hydrophilic excipient, usually present at from 99.99% to 5% of the powder, the methods may be applied more broadly to form dry powders comprising a variety of hydrophobic and hydrophilic components at different concentration ranges, including hydrophilic drugs and hydrophobic excipients.

The spray drying methods of the present invention are compatible with at least most hydrophilic pharmaceutical excipients, particularly including mannitol, povidone, pectin, lactose, sodium chloride, and sodium citrate. Use of the latter three excipients is particularly preferred for powders

intended for pulmonary delivery as they are "generally recognized as safe" (GRAS) for such applications. The methods are also suitable for use with numerous hydrophobic drugs and nutrients, including steroids and their salts, such as budesonide, testosterone, progesterone, estrogen, flunisolide, triamcinolone, beclomethasone, betamethasone; dexamethasone, fluticasone, methylprednisolone, prednisone, hydrocortisone, and the like; peptides, such as cyclosporin and other water insoluble peptides; retinoids, such as all-cis retinoic acid, 13-trans retinoic acid, and other vitamin A and beta carotene derivatives; vitamins D, E, and K and water insoluble precursors and derivatives thereof; prostagladins and leukotrienes and their activators and inhibitors including prostacyclin (epoprostanol), and prostaglandins E_1 E_2; tetrahydrocannabinol; lung surfactant lipids; lipid soluble antioxidants; hydrophobic antibiotics and chemotherapeutic drugs such as amphotericin B, adriamycin, and the like.

The spray drying methods can produce a uniform particle size distribution. For example, the mean particle diameter can be controlled below 10 μm, preferably below 5 μm, with a size distribution (standard deviation) less than $\pm$ 2 μm. The particles of the powders so produced have a minimum batch-to-batch variability in composition, and are physically and chemically stable. The powders have minimum residual organic solvents to the extent they may have been used in the spray drying process.

According to the method of the present invention, an aqueous solution of the hydrophilic component is prepared, typically by mixing in water under a vacuum or reduced pressure. The hydrophobic component is then suspended in the aqueous solution of the hydrophilic component to form a suspension. The hydrophobic components may be suspended in any of three ways, or a combination of them. First, the hydrophobic component may be mixed directly into the aqueous solution. Second, to aid in obtaining a uniform dispersion of the hydrophobic component, a surfactant can be added to the aqueous suspension of the hydrophilic component. Third, the hydrophobic component can be mixed with either a surfactant or

a water miscible organic solvent prior to the hydrophobic components being mixed with the aqueous solution of excipient. This may be done by mixing an organic solvent or dissolving or suspending a surfactant in a small amount of water, which is then mixed with the hydrophobic components. The resulting suspension is then mixed with the aqueous solution of excipient. The suspension is then spray dried to form particles comprising of both the hydrophilic and the hydrophobic components. Usually, the hydrophobic component will have an aqueous solubility less than 5 mg/ml, more usually below 1 mg/ml. The hydrophilic component will have a concentration in the aqueous solution in the range from 1 mg/ml to 100 mg/ml, usually from 5 mg/ml to 60 mg/ml, and the hydrophobic component is suspended in the solution to a concentration in the range from 0.01 mg/ml to 10 mg/ml, usually from 0.05 mg/ml to 5 mg/ml.

The hydrophobic component will be ground, comminuted, micronized, or otherwise rendered to a fine powder in order to enhance the stability and uniformity of the aqueous suspension. Preferably, the hydrophobic component powder will have a particle size in the range from 5 μm to 2 nm, more preferably from 2 μm to 20 nm and even more preferably from 800 nm to 50 nm. The use of sub-micron particles has been found to be particularly effective in maintaining a uniform dispersion of the hydrophobic component in the aqueous solution of the hydrophilic component prior to spray drying.

Powders prepared by the above method will be collected from the spray drier in a conventional manner for subsequent use. For use as pharmaceuticals and other purposes, it will frequently be desirable to disrupt any agglomerates which may have formed by screening or other conventional techniques. For pharmaceutical uses, the dry powder formulations will usually be measured into a single dose, and the single dose sealed into a package. Such packages are particularly useful for dispersion in dry powder inhalers, as described in detail below. Alternatively, the powders may be packaged in multiple-dose containers.

The present invention further comprises dry powder compositions produced according to the methods described above, as well as unit dose and multidose packages of such dried powder compositions containing a therapeutically effective amount of the dry powder.

The present invention further provides methods for aerosolizing a dry powder composition comprising the steps of providing an amount of dry powder composition produced by any of the methods described above and subsequently dispersing the dry powder composition into a flowing gas stream.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a spray drying system suitable for performing the methods of the present invention.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The present invention relates to methods for preparing compositions comprising ultrafine dry powders having both hydrophobic and hydrophilic components. The methods are particularly suitable for producing ultrafine pharmaceutical dry powders where the hydrophobic component is a hydrophobic drug and the hydrophilic component is a hydrophilic excipient. The present invention, however, may find use for preparing a variety of other compositions including pharmaceutical compositions having hydrophilic drugs and hydrophobic excipients and compositions intended for non-pharmaceutical applications. The methods rely on spray drying liquid media in which the components are solubilized or suspended. In particular, the hydrophilic component will be solubilized while the hydrophobic component is suspended.

The term "hydrophobic component" refers to materials which are insoluble or sparingly or poorly soluble in water. As used herein, such compositions will have a solubility below 10 mg/ml, usually below 1 mg/ml and sometimes below 0.01 mg/ml. Exemplary hydrophobic drugs include certain steroids, such as budesonide, testosterone, progesterone, estrogen, flunisolide, triamcinolone, beclomethasone,

betamethasone; dexamethasone, fluticasone, methylprednisolone, prednisone, hydrocortisone, and the like; certain peptides, such as cyclosporin cyclic peptide, retinoids, such as all-cis retinoic acid, 13-trans retinoic acid, and other vitamin A and beta carotene derivatives; vitamins D, E, and K and water insoluble precursors and derivatives thereof; prostagladins and leukotrienes and their activators and inhibitors including prostacyclin (epoprostanol), and prostaglandins E_1 E_2; tetrahydrocannabinol; lung surfactant lipids; lipid soluble antioxidants; hydrophobic antibiotics and chemotherapeutic drugs such as amphotericin B and adriamycin and the like.

The hydrophobic component will be suspended in an aqueous solution of the hydrophilic component prior to spray drying. In order to enhance the uniformity of dispersion of the hydrophobic component in the aqueous medium, it is desirable to provide the hydrophobic component as a fine powder having a particle size in the ranges set forth above. Most hydrophobic drugs and other components will be available from suppliers in a powder form. The particle size of the supplied powders, however, will usually be above the preferred ranges set forth above. In such cases, it will be desirable to further reduce the particle size by conventional size reduction techniques, such as grinding, comminuting, micronizing, microfluidizing, milling, pulverization, and the like. Preferred techniques for producing sub-micron and nanometer-sized particles are described in U.S. Patent Nos. 5,518,187; 5,510,118; and 5,534,270.

To further enhance the uniformity and concentration of the fine powder suspensions of the hydrophobic components, it can be useful to add a surfactant to the aqueous solution of the hydrophilic component. Suitable surfactants include lecithin, polysorbates, benzalkonium chloride, sorbitan esters, oleic acid, and the like. Preferred surfactants comprise lecithin or Tween 80, present at a concentration in the range from 0.05% by weight to 10% by weight. An additional method to enhance the uniformity of the fine particle suspensions of the hydrophobic components can be to wet the hydrophobic components with either a surfactant or a

water miscible organic solvent prior to the hydrophobic components being mixed with the aqueous solution of excipient. This may be done by mixing the organic solvent or dissolving or suspending the surfactant in a small amount of water, which is then mixed with the hydrophobic components. The resulting suspension is then mixed with the aqueous solution of excipient. The specific organic solvent chosen will depend upon the solubility of the hydrophobic components in the organic solvent/water mixture, since it is desirable to dissolve less than 30% of the hydrophobic components, preferably less than 20%. For budesonide, solvents that can be used include ethanol, methanol, acetone, and the like. Suitable surfactants include those mentioned above.

By "hydrophilic component," it is meant that the component is highly soluble in water and frequently capable of swelling and formation of reversible gels. Typical aqueous solubilities of hydrophilic components will be greater than 5 mg/ml, usually greater than 50 mg/ml, often greater than 100 mg/ml, and often much higher. In addition to their hydrophilic nature, the pharmaceutical excipients will generally be selected to provide stability, dispersibility, consistency and/or bulking characteristics to enhance the uniform pulmonary delivery of the dried powder composition to a patient. For pulmonary delivery, the excipients must be capable of being taken into the lungs with no significant adverse toxicological effects on the lungs. Exemplary hydrophilic excipients include carbohydrates and other materials selected from the group consisting of lactose, sodium citrate, mannitol, povidone, pectin, citric acid, sodium chloride, water soluble polymers, and the like. Particularly preferred are lactose, sodium chloride, sodium citrate, and citric acid which are generally accepted for pulmonary delivery in dry powder formulations.

The phrase "ultrafine dry powder" means a powder composition comprising a plurality of discrete, dry particles having the characteristics set forth below. In particular, the dry particles will have an average particle size below 10 μm, usually below 5 μm, preferably being in the range from

0.4 to 5 μm, more preferably from 0.4 to 4 μm. The average particle size of the powder will be measured as mass median diameter (MMD) by conventional techniques. A particular powder sizing technique uses a centrifugal sedimentary particle size analyzer (Horiba Capa 700). The powders will be capable of being readily dispersed in an inhalation device and subsequently inhaled by a patient so that the particles are able to penetrate into the alveolar regions of the lungs.

Of particular importance to the present invention, the ultrafine dry particle compositions produced by the method will have particle size distributions which enable them to target the alveolar region of the lung for pulmonary delivery of locally acting steroids, systemically acting proteins, and other biologically active materials that can be administered to or through the lungs. Such compositions advantageously may be incorporated into unit dosage and other forms without further size classification. Usually, the ultrafine dry powders will have a size distribution where at least 90% of the powder by weight will comprise particles having an average size in the range from 0.1 μm to 7 μm, with preferably at least 85% being in the range from 0.4 μm to 5 μm. Additionally, it is desirable that the particle size distribution avoid having an excess amount of particles with very small average diameters, i.e., below 0.4 μm.

The term "dry" means that the particles of the powder have a moisture content such that the powder is physically and chemically stable in storage at room temperature and is readily dispersible in an inhalation device to form an aerosol. Usually, the moisture content of the particles is below 10% by weight water, usually being below 5% by weight, preferably being below 3% by weight, or lower. The moisture content will usually be controlled by the drying conditions, as described in more detail below. The term "dry" further means that the particles of the powder have a moisture content such that the powder is readily dispersible in an inhalation device to form an aerosol. In some cases, however, non-aqueous medium may be used for dispersing the hydrophobic

component, in which case the aqueous content may approach zero.

The term "therapeutically effective amount" is the amount present in the composition that is needed to provide the desired level of hydrophobic drug in the subject to be treated to give the anticipated physiological response. This amount is determined for each drug on a case-by-case basis. The term "physiologically effective amount" is that amount delivered to a subject to give the desired palliative or curative effect. This amount is specific for each drug and its ultimate approval dosage level.

The therapeutically effective amount of hydrophobic drug will vary in the composition depending on the biological activity of the drug employed and the amount needed in a unit dosage form. Because the subject powders are dispersible, it is highly preferred that they be manufactured in a unit dosage form in a manner that allows for ready manipulation by the formulator and by the consumer. This generally means that a unit dosage will be between about 0.5 mg and 15 mg of total material in the dry powder composition, preferably between about 1 mg and 10 mg. Generally, the amount of hydrophobic drug in the composition will vary from about 0.01% w/w to about 95% w/w. Most preferably the composition will be about 0.05% w/w to about 25% w/w drug.

Referring now to Fig. 1, processes according to the present invention for preparing dispersible dry powders of hydrophobic and hydrophilic components comprise an atomization operation 10 which produces droplets of a liquid medium which are dried in a drying operation 20. Drying of the liquid droplets results in formation of the discrete particles which form the dry powder compositions which are then collected in a separation operation 30. Each of these unit operations will be described in greater detail below.

The atomization process 10 may utilize any one of several conventional forms of atomizers. The atomization process increases the surface area of the starting liquid. Due to atomization there is an increase in the surface energy of the liquid, the magnitude of which is directly proportional

to the surface area increase. The source of this energy increase depends on the type of atomizer used. Any atomizer (centrifugal, sonic, pressure, two fluid) capable of producing droplets with a mass median diameter of less than about 20 μm could be used. Preferred for the present invention is the use of two fluid atomizers where the liquid medium is delivered through a nozzle concurrently with a high pressure gas stream. Particularly preferred is the use of two-fluid atomization nozzles as described in copending application serial no. 08/644,681, which is capable of producing droplets having a median diameter less than 20 μm.

The atomization gas will usually be air which has been filtered or otherwise cleaned to remove particulates and other contaminants. Alternatively, other gases, such as nitrogen may be used. The atomization gas will be pressurized for delivery through the atomization nozzle, typically to a pressure above 5 psig, preferably being above 10 psig. Although flow of the atomization gas is generally limited to sonic velocity, the higher delivery pressures result in an increased atomization gas density. Such increased gas density has been found to reduce the droplet size formed in the atomization operation. Smaller droplet sizes, in turn, result in smaller particle sizes. The atomization conditions, including atomization gas flow rate, atomization gas pressure, liquid flow rate, and the like, will be controlled to produce liquid droplets having an average diameter below 20 μm as measured by phase doppler velocimetry.

The drying operation 20 will be performed next to evaporate liquid from the droplets produced by the atomization operation 10. Usually, the drying will require introducing energy to the droplets, typically by mixing the droplets with a heated gas which causes evaporation of the water or other liquid medium. Preferably, the heated gas stream will flow concurrently with the atomized liquid, but it would also be possible to employ counter-current flow, cross-current flow, or other flow patterns.

The drying rate may be controlled based on a number of variables, including the droplet size distribution, the

inlet temperature of the gas stream, the outlet temperature of the gas stream, the inlet temperature of the liquid droplets, and the manner in which the atomized spray and hot drying gas are mixed. Preferably, the drying gas stream will have an inlet temperature of at least 70°C. The outlet temperature will usually be at least about 40°C. The drying gas will usually be air or nitrogen which has been filtered or otherwise treated to remove particulates and other contaminants. The gas will be moved through the system using conventional blowers or compressors.

The separation operation 30 will be selected in order to achieve very high efficiency collection of the ultrafine particles produced by the drying operation 20. Conventional separation operations may be used, although in some cases they should be modified in order to assure collection of sub-micron particles. In an exemplary embodiment, separation is achieved using a filter medium such as a membrane medium (bag filter), a sintered metal fiber filter, or the like. Alternatively, and often preferably, separation may be achieved using cyclone separators, although it is usually desirable to provide for high energy separation in order to assure the efficient collection of sub-micron particles. The separation operation should achieve collection of at least 80% of all particles above 1 μm in average particle size, preferably being above 85%, more preferably being above 90%, and even more preferably being above 95%, in collection efficiency.

In some cases, a cyclone separator can be used to separate very fine particles, e.g. 0.1 μm, from the final collected particles. The cyclone operating parameters can be selected to provide an approximate cutoff where particles above about 0.1 μm are collected while particles below 0.1 μm are carried over in the overhead exhaust. The presence of particles below 0.1 μm in the pulmonary powder is undesirable since they will generally not deposit in the alveolar regions of the lungs, but instead will be exhaled.

The present invention relies on proper selection of the liquid medium or media for suspending the hydrophobic drug

or other component and hydrophilic excipient or other component. In particular, the liquid medium may be water which will fully dissolve the hydrophilic excipient or other component to form a solution. The hydrophobic component is then suspended in the solution, and the solution spray dried as described above to form a powder having particles comprising a mixture of the dried hydrophilic and hydrophobic components. This approach is advantageous in that it can avoid the use of organic solvents. It is important, however, that the hydrophobic drug be adequately suspended in the mixing vessel and in the supply lines to the spray dryer so that there is minimum settling from the aqueous medium prior to spray drying. It is also important that the hydrophobic drug be in a powder form with an average particle size below 5 μm, preferably below 4 μm, and even more preferably below 2.5 μm to minimize the preferential accumulation of drugs in certain individual particles.

Once the dry powders have been prepared, they may be packaged in conventional ways. For pulmonary pharmaceutical applications, unit dosage forms may comprise a unit dosage receptacle containing a dry powder. The powder is placed within a suitable dosage receptacle in an amount sufficient to provide a subject with drug for a unit dosage treatment. The dosage receptacle is one that fits within a suitable inhalation device to allow for the aerosolization of the dry powder composition by dispersion into a gas stream to form an aerosol and then capturing the aerosol so produced in a chamber having a mouthpiece attached for subsequent inhalation by a subject in need of treatment. Such a dosage receptacle includes any container enclosing the composition known in the art such as gelatin or plastic capsules with a removable portion that allows a stream of gas (e.g., air) to be directed into the container to disperse the dry powder composition. Such containers are exemplified by those shown in U.S. Patents 4,227,522 issued October 14, 1980; 4,192,309 issued March 11, 1980; and 4,105,027 issued August 8, 1978. Suitable containers also include those used in conjunction with Glaxo's Ventolin Rotohaler® brand powder inhaler or Fison's Spinhaler®

brand powder inhaler. Another suitable unit-dose container which provides a superior moisture barrier is formed from an aluminum foil plastic laminate. The pharmaceutical-based powder is filled by weight or by volume into the depression in the formable foil and hermetically sealed with a covering foil-plastic laminate. Such a container for use with a powder inhalation device is described in U.S. patent 4,778,054 and is used with Glaxo's Diskhaler® (U.S. Patents 4,627,432; 4,811,731; and 5,035,237). Preferred dry powder inhalers are those described in U.S. Patent application serial nos. 08/309,691 and 08/487,184, assigned to the assignee of the present invention. The latter application has been published as WO 96/09085.

The following examples are offered by way of illustration, not by way of limitation.

EXPERIMENTAL

The following materials were used:

Budesonide (micronized to a median particle size of 1-2 μm; Steraloids)

Lactose monohydrate (NF grade; Foremost Ingredient Group)

Sodium Chloride (reagent grade from VWR and USP grade from EM Industries)

Sodium citrate, dihydrate (USP grade; Mallinckrodt)

Benzalkonium chloride (50% solution, USP/NF grade, Spectrum)

Lecithin (USP/NF grade, Spectrum

Oleic acid (NF grade, J.T. Baker)

Deionized water

Ethanol, 200 proof (USP/NF; Spectrum Chemical Mfg. Corp.)

Acetone (for histology; EM Industries)

Methanol (HPLC grade; EM Industries)

All batches were spray dried on Buchi 190 Mini Spray Dryers, with nozzles and cyclones that were designed to generate and catch very fine particles. For formulations that utilized organic solvents, a Buchi 190 Mini Spray Dryer was used that was modified so that it was supplied with nitrogen as the gas source and equipped with an oxygen sensor and other safety equipment to minimize the possibility of explosion.

The solution feed rate was 5 ml/minute, inlet temperature was adjusted to obtain the outlet temperature noted in each example, the top of the cyclone in some runs was jacketed and cooled to a temperature of about 30°C, the drying air (or nitrogen) flow rate was about 18 SCFM, and the atomizing air was supplied at 0.5 to 1.5 SCFM. The powders were further dried in the collector for 5-15 minutes (most often for 5 minutes) by maintaining the targeted outlet temperature and air volume after the feeding of the liquid formulation was completed.

Particle size was determined with a Horiba Particle Size Analyzer, model CAPA 700. Median particle size refers to the volume based particle size distribution of the prepared bulk powders determined via centrifugal sedimentation as follows. A sample of the powder was suspended in an appropriate liquid medium (one that minimizes solubilizing the particle), sonicated to break up the agglomerates, and then centrifuged. The median particle size was determined by measuring the sedimentation rate during centrifugation. This method provides the median size of the "primary" particle, that is, the size of the particles produced by the manufacturing process, plus potential modification during sample preparation. Because these formulations are composed of both water soluble and water insoluble materials, it is likely that the suspension step during sample preparation does to some extent solubilize part of the particle, and thereby modify the particle size that is determined. Therefore, the resultant particle sizes should be viewed as estimated values, rather than absolute values.

Moisture content was determined by the Karl-Fischer Reagent titrimetric method.

Delivered dose efficiency refers to a measure of the percentage of powder which is drawn out of a blister package and which exits the mouthpiece of an inhaler device as described in U.S. Patent Application Serial No. 08/487,184. Delivered dose efficiency is a measure of efficiency for the powder package/device combination. The test was performed by connecting a vacuum system to the device mouthpiece. The

vacuum system was set to be similar to a human inhalation with regard to volume and flow rate (1.2 liters total at 30 liters/minute). A blister package containing 0.5 to 10 mg of the formulation to be evaluated (2 to 5 mg of powder was used for the following examples) was loaded into a device which was held in a testing fixture. The device was pumped and fired, and the vacuum "inhalation" was switched on. The aerosol cloud was thus drawn out of the device chamber by the vacuum, and the powder was collected on a filter placed between the mouthpiece and the vacuum source. The weight of the powder collected on the filter was determined. Delivered dose efficiency was calculated by multiplying this weight by one hundred and dividing by the fill weight in the blister. A higher number was a better result than a lower number.

MMAD (mass median aerodynamic diameter) refers to a measure of the particle size of the aerosolized powder. MMAD was determined with an Andersen cascade impactor. In a cascade impactor the aerosolized powder (which was aerosolized using an inhaler device as described in U.S. Patent Application Serial No. 08/487,184) enters the impactor via an air stream, and encounters a series of stages that separate particles by their aerodynamic diameter (the smallest particles pass farthest down the impactor). The amount of powder collected on each stage is determined gravimetrically, and the mass median aerodynamic diameter is then calculated.

Suspending budesonide in aqueous excipient solutions

Manufacturing procedure:

The hydrophobic component was suspended in any of three different ways:

(1) the hydrophobic component was mixed directly into the aqueous solution (this method was used for all of the examples in Table 1, except for batches 329-56 and 329-58),

(2) a surfactant or a water miscible organic solvent was added to the aqueous solution prior to the hydrophobic component being added (this

method was used for example batches 329-56 and 329-58 in Table 1),

(3) the hydrophobic component was mixed with either a surfactant and/or a water miscible organic solvent prior to the hydrophobic component being mixed with the aqueous solution of excipient (this method was used for all of the examples in Table 2). This was done by dissolving an organic solvent and/or dissolving or suspending a surfactant in about 10% of the total water (using sonication if necessary), and this solution or suspension was then mixed with the hydrophobic component using sonication. The aqueous solution of excipient (which was prepared by dissolving the excipients in water with mixing) was then mixed with the concentrated suspension of the hydrophobic component.

Mixing of the suspension was continued prior to and throughout spray drying. The suspension was spray dried. The powders were then passed through a screen (a 35 mesh screen was used). This last step may not always be required, but it has been found that passing the powders through a screen will often decrease the blister to blister delivered dose efficiency variability.

Many different mixing techniques for preparation of the suspension have been and may be used, but one that has been found to be particularly useful, when a wetting agent (a surfactant or an organic solvent) was not utilized, was to weigh all of the powders into the mixing vessel, add half of the liquid medium, deaerate the mixture under vacuum, then mix the powders with the liquid medium with a magnetic stirrer under the vacuum. The next steps were to sonicate the resulting suspension while maintaining the vacuum, slowly release the vacuum and add the rest of the liquid medium (rinse down the container walls while doing so), pull a vacuum again and deaerate the suspension, stir it again and then

sonicate it again (all under vacuum), and then slowly release the vacuum and continue mixing the suspension prior to and throughout spray drying, being careful to not incorporate air into the suspension. This reduced the creation of foam and deposition of drug substance on the mixing vessel walls.

Tables 1 and 2, below, show the spray drier atomization air pressure and outlet air temperature, the quantitative composition of example formulations, a description of the particle morphology, the moisture content, particle size, and delivered dose efficiency or MMAD of the resultant powders. Where the powders have been passed through a 35 mesh screen, the delivered dose efficiency results are preceded by the word "screened."

TABLE 1

Suspending budesonide in aqueous excipient solutions

Batch No., Formula No. (Spray Drier Atomization Air Pressure/ Outlet Air Temperature)	Quantitative Composition		Particle Morphology	Moisture Content	Particle Size (μm)	Delivered Dose Efficiency
329-8 B-1 (40PSI/77°C)	Budesonide Lactose DI water	50 mg 950 mg 100 ml	Smooth spheres	1.93%	2.32	41.5% (RSD=13) Screened: 41.3% (RSD=15)
329-9 B-2 (40PSI/77°C)	Budesonide Sodium Chloride DI water	50 mg 950 mg 100 ml	Spheres made up of small cubes	0.88%	1.50	41.1% (RSD=15) Screened: 43.2% (RSD=7)
329-61 B-2 (40PSI/77°C)	Budesonide Sodium Chloride DI water	350 mg 6650 mg 700 ml		0.91%	1.57	Screened: 34.5% (RSD=9)
329-10 B-3 (40PSI/80°C)	Budesonide Sodium Citrate DI water	49 mg 949 mg 100 ml	Smooth spheres	4.23%	2.74	52.6% (RSD=10) Screened: 52.4% (RSD=9)
329-11 B-4 (40PSI/79°C)	Budesonide Lactose Sodium Chloride Sodium Citrate DI water	49 mg 317 mg 317 mg 316 mg 100 ml	Smooth spheres	2.00%	2.45	53.0% (RSD=20) Screened: 70.7% (RSD=4) 56.2% (RSD=10) upon retesting
329-60 B-4 (40PSI/79°C)	Budesonide Lactose Sodium Chloride Sodium Citrate DI water	350 mg 2217 mg 2217 mg 2216 mg 700 ml		2.07%	2.04	Screened: 53.2% (RSD=9)

TABLE 1 (continued)

329-35-S B-7 (40PSI/77°C)	Budesonide Lactose Sodium Chloride DI water	50 mg 475 mg 475 mg 100 ml	Smooth spheres	0.82%	2.37	Screened: 57.3% (RSD=4)
329-69-S B-7 (40PSI/77°C)	Budesonide Lactose Sodium Chloride DI water	350 mg 3325 mg 3325 mg 700 ml		1.00%	2.16	Screened: 59.5% (RSD=9)
329-73-S B-7 (40PSI/77°C)	Budesonide Lactose Sodium Chloride DI water	350 mg 3325 mg 3325 mg 700 ml		1.02%	1.78	Screened: 63.3% (RSD=8)
329-56 B-20 (40PSI/78°C)	Budesonide Lactose Sodium Chloride 95:5 water:acetone	50 mg 475 mg 475 mg 100 ml		0.79%	2.05	62.3% (RSD=19)
329-58 B-22 (40PSI/77°C)	Budesonide Lactose Sodium Chloride 95:5 water:methanol	50 mg 475 mg 475 mg 100 ml		0.70%	1.88	55.7% (RSD=19)
329-36-S B-8 (40PSI/80°C)	Budesonide Sodium Chloride Sodium Citrate DI water	50 mg 475 mg 475 mg 100 ml	Rough surfaced spheres	1.91%	2.01	Screened: 44.2% (RSD=7)
329-37-S B-9 (40PSI/80°C)	Budesonide Lactose Sodium Citrate DI water	50 mg 475 mg 475 mg 100 ml	Smooth spheres	2.20%	1.79	Screened: 44.1% (RSD=6)

Table 2
Suspending Budesonide In Aqueous Excipient Solutions

Batch No., Formula No., (Spray Drier Atomization Air Pressure/Outlet Air Temperature)	Quantitative Composition		Particle morphology	Moisture Content	Particle Size (μm)	Powder MMAD (μm)
446-68-S B-40 (105PSI/80°)	Budesonide Lactose Sodium Chloride Lecithin 99:1 water:EtOH	75 mg 690 mg 690 mg 40 mg 100 ml	Slightly rough spheres	0.44%	1.44	Screened: 2.81
446-70-S B-41 (105PSI/80°)	Budesonide Lactose Sodium Chloride Lecithin 99:1 water:EtOH	75 mg 690 mg 690 mg 4 mg 100 ml	Slightly rough spheres	0.69%	1.44	Screened: 3.11
446-76-S B-44 (105PSI/80°)	Budesonide Lactose Sodium Chloride BAC 99:1 water:EtOH	75 mg 690 mg 690 mg 40 mg 100 ml	Golf ball surfaced spheres	0.80%	1.14	Screened: 2.59
446-80-S B-46 (105PSI/80°)	Budesonide Lactose Sodium Chloride Oleic Acid 99:1 water:EtOH	75 mg 690 mg 690 mg 40 mg 100 ml	Smooth spheres	0.87%	1.34	Screened: 2.77
529-18 B-34 (105PSI/80°C)	Budesonide Lactose Sodium Chloride BAC DI water	187.5 mg 656 mg 656 mg 0.075 mg 100 ml		0.84%	1.39	Screened: 2.05

Table 2 (Continued)

Batch No., Formula No., (Spray Drier Atomization Air Pressure/Outlet Air Temperature)	Quantitative Composition		Particle morphology	Moisture Content	Particle Size (μm)	Powder MMAD (μm)
529-24 B-104 (105PSI/80°C)	Budesonide Lactose Sodium Chloride Lecithin DI water	187.5 mg 636 mg 636 mg 40.5 mg 100 ml		1.06%	1.82μm	Screened: 1.85
529-22 B-102 (105PSI/80°C)	Budesonide Lactose Sodium Chloride Lecithin DI water	187.5 mg 656 mg 656 mg 0.075 mg 100 ml		0.90%	1.29μm	Screened: 1.86 DDE*= 58.0% (RSD=8)
529-26 B-105 (105PSI/80°C)	Budesonide Lactose Sodium Chloride Lecithin 99:1 water:EtOH	187.5 mg 656 mg 656 mg 0.075 mg 100 ml		1.67%	1.46μm	Screened: 2.05

* DDE = Delivered Dose Efficiency

Although the foregoing invention has been described in some detail by way of illustration and example, for purposes of clarity of understanding, it will be obvious that certain changes and modifications may be practiced within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method for preparing a dry powder composition, said method comprising:

preparing an aqueous solution of a hydrophilic component;

suspending a hydrophobic component in the aqueous solution to form a suspension; and

spray drying the suspension to form particles comprising a mixture of the hydrophilic and hydrophobic components.

2. A method as in claim 1, wherein the hydrophobic component has a solubility in water less than 5 mg/ml.

3. A method as in claim 2, wherein the hydrophilic component has a concentration in the range from 1 mg/ml to greater than 50 mg/ml and the hydrophobic component is suspended to a concentration below 10 mg/ml.

4. A method as in claim 1, wherein the hydrophobic component comprises a hydrophobic drug.

5. A method as in claim 4, wherein the hydrophobic drug is a steroid selected from the group consisting of budesonide, testosterone, progesterone, estrogen, flunisolide, triamcinolone, beclomethasone, betamethasone, dexamethasone, fluticasone, methylprednisolone, prednisone, hydrocortisone.

6. A method as in claim 4, wherein the hydrophobic drug comprises a peptide, a retinoid, vitamin D, vitamin E, vitamin K, precursors and derivatives of these vitamins, a prostaglandin, a leukotriene, tetrahydrocannabinol, lung surfactant lipid, an antioxidant, a hydrophobic antibiotic, or a chemotherapeutic drug.

7. A method as in claim 1, wherein the hydrophilic component comprises an excipient for the hydrophobic drug.

8. A method as in claim 7, wherein the hydrophilic excipient comprises a material selected from the group consisting of lactose, sodium citrate, mannitol, povidone, pectin, citric acid, sodium chloride, and mixtures thereof.

9. A method as in claim 1, wherein a surfactant and/or a water miscible organic solvent is added to enhance the uniformity of the suspension of the hydrophobic agent.

10. A method as in claim 9, wherein the surfactant comprises a material selected from the group consisting of lecithin, polysorbates, benzalkonium chloride, sorbitan esters, and oleic acid.

11. A method as in claim 1, further comprising mixing the hydrophobic component into the aqueous solution under a vacuum and/or screening the spray dried particles to disrupt agglomerates.

12. A method as in anyone of claims 1 to 11, further comprising:

measuring a single dosage of the dry powder; and

sealing the single dosage in a package.

13. A method as in claim 1, wherein prior to suspension in the aqueous solution, the hydrophobic component has a particle size in the range from 5 μm to 20 nm.

14. A method as in claim 13, wherein the particle size is in the range from 800 nm to 50 nm.

15. A dry powder composition prepared according to any of claims 1 to 14.

16. A unit dose of a dry powder composition comprising a unit dose receptacle having a therapeutically effective amount of a dry powder composition according to any of claims 1 to 14.

17. A method for aerosolizing a dry powder composition said method comprising:

providing an amount of a dry powder composition according to any of claims 1 to 14; and

dispersing the dry powder composition into a flowing gas stream.

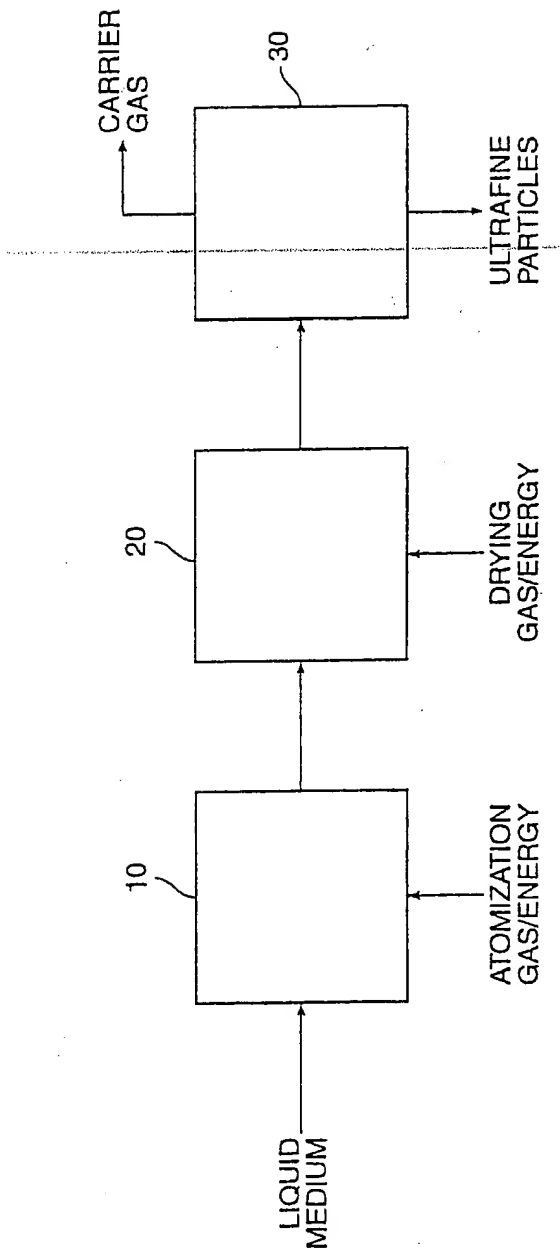
CARRIER GAS
30
ULTRAFINE PARTICLES
20
DRYING GAS/ENERGY
10
ATOMIZATION GAS/ENERGY
LIQUID MEDIUM

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/23905

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : A61K 9/14; B29B 9/00
US CL :424/489; 264/12,13,14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 424/489; 264/12,13,14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,590,206 A (FORRESTER ET AL) 20 May 1986 (20-05-86), entire document.	1-17
Y	US 5,260,306 A (BOARDMAN ET AL) 09 November 1993 (09-11-93), entire document.	1-17
X	US 4,486,435 A (SCHMIDT ET AL) 04 December 1984 (04-12-84), example 1.	1,4,6,7,14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 13 MARCH 1998	Date of mailing of the international search report 14 APR 1998
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